

SITE CRITERIA FOR CONVERSION OF SAGEBRUSH LANDS TO GRASSLANDS

BY

L. M. SHOWN, R. S. ARO, R. F. MILLER, AND F. A. BRANSON

CONVERSION PRACTICES ON PUBLIC LANDS



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Site criteria for conversion of sagebrush lands to grasslands

Erratta

- (1) On the cover, directly above the photograph, the work conservation should appear in place of conversion.
- (2) Page 10, second sentence should read: The average weight, in grams, of grass for the five 9.6-square foot plots at each site was obtained.
- (3) Page 20, Table 2: (a) The big sagebrush failure group is composed of sites where big sagebrush was removed and the seeding of grass failed. (b) The high and low crested wheatgrass yields of the Marden Brush Cutter Group are reversed.
- (4) Page 26, seventh line down, the word six should appear instead of five.

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INTRODUCTION

Several million acres of sagebrush range in the western United States has been treated by various methods in attempts to produce more forage and reduce erosion. Control of poisonous or otherwise undesirable plants as well as control of the sagebrush was an additional objective in some places. The treatments commonly employed have either reduced or eliminated the sagebrush, much of which was big sagebrush (Artemisia tridentata). Successful treatments have released soil moisture to naturally or artificially seeded species, mainly perennial grasses. The achievement of the practical goals of increased forage production and increased protection of the soil from erosion has made a more beneficial use of the soil-moisture water resource.

In certain areas, the increase in forage production already realized has allowed reductions in grazing intensities on partially depleted ranges nearby. The result has been a general improvement of the plant cover on those nearby ranges. The conversion of additional grass-depleted sagebrush lands to grassland will lead to the improvement of many more partially damaged ranges.

Some sagebrush conversion projects have completely failed or have been only partially successful. Drought, annual weed competition, improper planting, improper grazing, insufficient control of sagebrush or selection of areas that were normally too dry have caused seeding failures in some places. In other places the reasons for failure are not obvious but are thought to be related to insufficient available soil-moisture.

This study had several purposes. One objective was to determine the influence of moisture absorption and storage properties of soils on the distribution of several species of sagebrush and associated shrubs. A concurrent objective was to investigate the effect of soil-moisture factors on the establishment and production of crested wheatgrass after the sagebrush was eliminated. A general evaluation of some of the Bureau of Land Management sagebrush conversion projects, particularly those that involved plowing and seeding, was made during the course of this study.

Assistance in this study by Mr. Gary A. Tompkins, formerly of the U.S. Geological Survey, is greatly appreciated. The cooperation of Bureau of Land Management district personnel in supplying information about the projects is gratefully acknowledged.

PROCEDURES

The broad geographic distribution of the seedings studied (see fig. 1) provided representation of many of the various sagebrush habitats. Data from various environments are often difficult to interpret and correlate, but any general principles which can be shown to hold true regardless of environmental variations, greatly contribute to a better understanding of the subject by all concerned.

A distinctive feature of this study was the selection of several sites on some of the seedings. The sites at each seeding represented both variations in the composition or vigor of the untreated vegetation and variations of seeded grass establishment. The vegetation variations were thought to be due to soil differences as climate was assumed to be the same for all sites on each seeding.

The climates of the areas where the seedings are located are either arid or semiarid. The estimated annual precipitation ranges from 8 to 14 inches. Weather Bureau records show that the distribution of the precipitation, mean seasonal temperature, amounts of wind, and evaporation are similar among some of the seedings. These factors are variable among other seedings.

The altitudes of the seedings range from 4,300 to 7,600 feet.

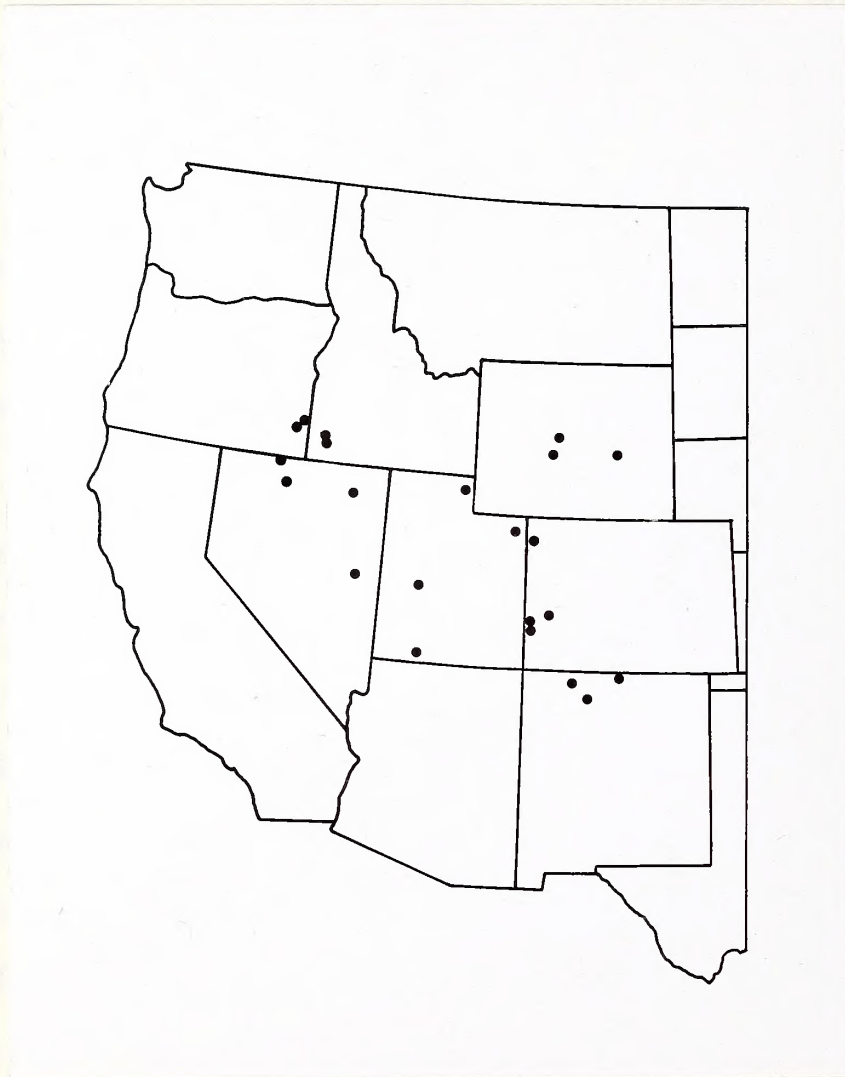


Figure 1.--Approximate locations of the seedings where sites were sampled.

The soils of the seedings studied are developed in materials from several geologic sources. The soils of most of the seedings in the Basin and Range, and Columbia Plateau Provinces are developed in stream, lake, or alluvial fan sediments. Most of these sediments were derived from extrusive volcanic materials. The basalts and volcanic ash tend to weather relatively rapidly and furnish silt and clay materials. The resultant soils are usually medium- or fine-textured. Rhyolites and welded tuffs contain more silica and tend to weather much slower. These slower weathering rocks, together with igneous intrusive and metamorphic rocks transported from the mountains, have usually provided the abundance of coarse fragments which are found in some of the soils.

Sandstones are the main parent material of most of the coarse- to medium-textured soils found at the seedings in the Rocky Mountain and Colorado Plateau regions. Interbedded shales and sandstones are the dominant parent material of the soils of the Wyoming seedings. Owing to more even topography, the soils of the Rocky Mountain and Colorado plateau seedings are more uniform than most of the soils at the Basin and Range, and Columbia Plateau seedings.

Site selection

Fifty-one study sites were selected at the edges of 22 Bureau of Land Management crested wheatgrass (Agropyron desertorum) seedings. Each site consisted of an untreated area and an adjacent treated area. Most of the seeded areas had been plowed with either a disk

plow or offset disk to eliminate the sagebrush. The areas had been seeded with either a drill or some type of broadcasting equipment. All seedings were at least 2 years old with the ages ranging up to 14 years.

Two to six sites were selected on each of 11 of the seedings where variations in the vegetation existed (fig. 2). At each of the other 11 seedings, the vegetation on both the treated and untreated areas was relatively uniform. Therefore, only one generally representative site was selected on those seedings.

Sites were selected where water apparently did not pond or channel. Most sites were flatlying or on slopes of up to six percent; a few sites were on slopes of up to 13 percent.

The following information was obtained from the Bureau of Land Management district records: methods and dates of sagebrush control, methods and dates of seeding, species seeded and seeding rates, grazing schedules, precipitation estimates and the general weather conditions for about two years after the treatments.

U.S. Weather Bureau records and a normal annual precipitation map (U.S. Department of Commerce, 1963) were used to supplement the climatic data for all of the seedings.

Field sampling

Soil pits were dug, in both the treated and adjacent areas, to the depth of normal wetting as indicated by (1) changes in root concentrations, structure, and hardness, and (2) the presence of bedrock or caliche layers. The soils were sampled in layers which generally correspond to the A, AB, B, BC, and C horizons. In some profiles, not all of the above-mentioned layers were identifiable. At the time of sampling, texture, structure, dry consistence, and a rock-content estimate were determined for each soil sample. Lime content and root density estimates were made for each sample. The rock type(s) and the soil parent material(s) at each site were noted.

Line intercept and height measurements were made to describe the shrub species on the untreated areas and on treated areas where shrubs had survived the treatments or had reinvaded after treatment.

Five 9.6-square foot yield plots were clipped on each treated area that had some seeded grass present. Crested wheatgrass yields were estimated on three sites where the growth of grass had been delayed by spring drought. Utilization estimates were made for the sites that had been grazed, and the yields on those sites were adjusted accordingly. Yield plots were also clipped on the untreated areas that had abundant understories of cheatgrass brome (Bromus tectorum) and Sandberg bluegrass (Poa secunda).

Species lists were made of the grasses and forbs that constituted usually sparse understories on the untreated areas. Such lists were also prepared for the treated areas, especially those where the artificially seeded grass stands were poor or nonexistent.





Figure 2.--These three sites along the edge of one seeding in north-central Nevada represent slight variations of native vegetation and different degrees of crested wheatgrass establishment in response to plowing and drilling. The conversion to crested wheatgrass was successful on the upper site on the opposite page; it was moderately successful on the lower site. The conversion was a failure on the above shown site which had an annual mustard on it.

Laboratory techniques

All grass samples were dried for 24 hours at 105 degrees centigrade before they were weighed. The average weight^{ingrams} of grass for the five 9.6-square foot plots at each site was obtained. The weights were multiplied by 10 to convert the yields to units of pounds per acre.

Each soil sample was saturated by slowly mixing distilled water with the previously weighed oven-dry soil (methods 2 and 27B, U.S. Salinity Laboratory Staff, 1954). The moisture content of each saturated sample was calculated by dividing the weight of the water added by the weight of the dry soil; the values were converted to percentages by multiplying by 100.

The moisture content of saturated soil was used in this study as an index of the moisture-holding capacity of the soil. The U.S. Salinity Laboratory Staff (1954) reports that the moisture content of saturated soil "is directly related to the field moisture range"; one-half the moisture content of saturated soil is suggested as an approximation of the field capacity of the soil. Field capacity is defined as the moisture content of a soil after it has been saturated and after free drainage has practically ceased.

Besides being simple and rapid, this procedure at least partially allows the effects of gravel and stable soil structure to be included in the measurement.

The electrical resistance of each saturated soil sample was determined with a probe cell coupled to a Wheatstone bridge. The resistance values were converted to electrical conductivity values by means of a standard formula (method 4a U.S. Salinity Laboratory Staff, 1954). The electrical conductivity of a soil paste increases as the salt content of the soil increases. Therefore, the electrical conductivity values were used as an index of the salinity of the soil. The pH of each saturated soil sample was measured with a glass electrode pH meter to determine the soil reaction and to check for excess sodium.

RESULTS AND DISCUSSION

The success or failure of attempts to convert sagebrush lands to grasslands in arid or semiarid regions appears to be the result of a complex interaction of soil, climate, treatment methods, and grazing management. In this study, much of the data pertains to the soil and vegetation. Therefore, the apparent effect of soil on crested wheatgrass yields will be discussed first.

Relation of moisture characteristics of the soils to grass production

The effect of soil moisture-holding capacity on crested wheatgrass establishment and subsequent forage production was evaluated by plotting the crested wheatgrass yield against the moisture content of the saturated surface-soil (fig. 3). The value for the surface-soil was used because the surface-soil, composed of the A and AB horizons, is the part of the soil profile most important in affecting germination and early seedling development of grasses.

The mean value for the moisture content at saturation of all of the surface-soil samples is 33.3 percent. The standard deviation from the mean is 7.8 percent. Simply stated, the standard deviation is a measure of the average variation of the values from the mean value (Snedecor, 1946). The vertical lines of the medium bar in figure 3 are placed at the saturation moisture values equal to plus and minus one standard deviation from the mean saturation moisture value. Since the frequency distribution of the surface-soil saturation moisture values is normal, two-thirds (34) of the values lie in the medium soil saturation range. Nine values occur in the low range and seven in the high range.

The crested wheatgrass yields for each soil-moisture group range from none up to the value indicated by the top of each bar in figure 3. The horizontal lines dividing the bars mark the yield means. The three yield ranges overlap considerably due to there being extreme variability in the yields of the low and medium groups, and some poor yields in all of the groups, but there are meaningful differences among the yield means. The yield means are 341, 575, and 139 pounds per acre for the low, medium, and high soil-moisture groups, respectively. The mean yield for all sites is 485 pounds per acre.

Perennial grass production on the untreated areas was usually very low and for practical purposes was considered negligible. Therefore, the crested wheatgrass yields shown in figure 3 represent either increases or no change in grass production due to the treatments. On a few sites, fair stands of native perennial grasses were reduced by the plowing treatments. However, on a few other sites there were

noticeable increases in the native perennial grass stands as a result of the sagebrush eliminations and grazing reductions.

For each soil group, Table 1 shows the percentage of sites having yields which equaled or exceeded each indicated yield level. Another way to interpret the data of Table 1 is to consider each value as the probability, per 100 chances, for the crested wheatgrass yield either equaling or exceeding the indicated yield when the moisture content of the saturated surface-soil of the site is known. To do this, it must be assumed that the data of Table 1 are representative of the sagebrush type and its inherent environments. The probability that the yield will be below a given level is 100 minus the percentage values shown in Table 1. As an example, the chances are nearly even (47 to 53) that 400 pounds of grass per acre will result from conversion of sites that have a saturated surface-soil moisture content value in the medium group.

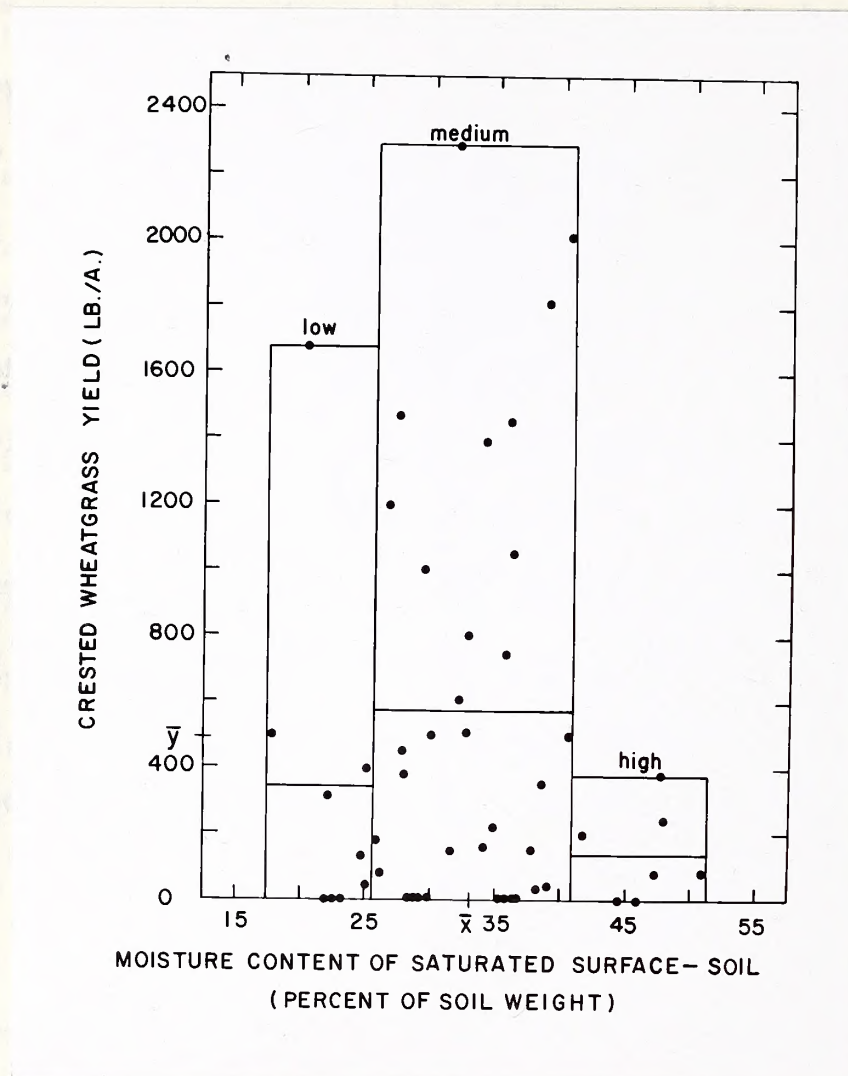


Figure 3.--The relation of the moisture contents of the saturated surface-soils to the crested wheatgrass yields of all of the sites. Highest yields occur on soils with medium moisture-holding capacities per unit of soil depth. These soils are commonly sandy loams, loams or silt loams and usually are permeable to a depth of at least 50 centimeters (20 inches). The line which divides each bar marks the grass yield mean for that soil group. The \bar{y} designates the mean yield of all sites and the \bar{X} designates the mean moisture content of saturation for all of the surface soils.

Table 1.--The percentage of sites within each soil group (fig. 3)
that equaled or exceeded the indicated yield levels

Crested wheatgrass (pounds per acre)	Surface-soil moisture group		
	Low	Medium	High
100	55	68	43
200	44	56	43
400	33	47	0
800	11	29	0
1,600	11	9	0

For each yield level, except the one of 1,600 pounds, the probability that the indicated yield will be equaled or exceeded is highest for the medium soils group. The probability of 11 for the 800 and 1,600 pound levels for the low saturation percentage soils group is of little significance because there is only one yield exceeding 800 pounds per acre in the low soils group (fig. 3).

It is common knowledge that the yield of grass at a particular location varies with annual precipitation. The precipitation was about average or above average for most sites of this study when they were sampled. Therefore, some yields may tend to be higher than the long-term average yields. Also, some of the yields may exceed long-term average yields because many of the seedings were young, having been planted since 1960. Hull and Klomp (1966) have referenced several studies which showed that crested wheatgrass yields were highest 2 to 5 years after seeding, followed by a decline to a level of long-time

productivity. Other workers cited by Hull and Klomp (1966) have stated that highest crested wheatgrass yields occurred during years of most favorable precipitation, regardless of the ages of the stands.

Due to droughty weather, several of the sites seeded since 1960 had rather poor stands of grass. Under proper management these stands may improve during favorable moisture years such as those prevailing since 1963. Noticeable improvement of a crested wheatgrass stand was observed between 1963 and 1965 on a seeding near Ely, Nevada.

The data show that the best yields can be expected on soils with medium moisture-holding properties. These are the soils which have the most optimum balance among the properties of moisture infiltration, moisture-retention capacity, and moisture-availability to plants. In soils having low moisture-holding capacities, infiltration is usually excellent, but moisture stored per unit depth of soil is low. Clayey soils have high moisture-holding capacities, but infiltration into them is slow and more of the precipitation results in runoff. The result is that less moisture is stored in the clayey soils, and some of the moisture that is stored is not available at a rate rapid enough to sustain plant growth.

The soils of the medium group generally are sandy loam, loam, or silt-loam in texture at the surface, with the subsoils usually being somewhat finer textured. These soils are usually loose¹ to moderately

¹ Terminology after U.S. Soil Survey Staff, 1951.

hard in dry consistence and have vesicular, platy, or subangular blocky structure in the surface soil and subangular blocky, angular blocky, or crumb structure in the subsoil. Soils having these properties are normally permeable, and absorb and hold available to plants much of the water that results from all except high-intensity precipitation events. Reynolds and Springfield (1953), after studying the results of attempts to convert sagebrush land to crested wheatgrass in New Mexico and Arizona, concluded that "An ideal soil for maximum herbage production is one at least two feet deep having a well-developed profile of sandy loam surface two to six inches deep underlain by a clay of blocky structure."

The soils included in the low moisture-retention group are either sandy, extremely gravelly, or cobbly. The permeability of sandy or gravelly soils is generally excellent. However, these soils usually do not have enough particle-surface area or pores of a sufficiently small diameter to retain an adequate quantity of water in the root zone of crested wheatgrass seedlings to sustain them through periods of little or no precipitation. Nonetheless, many sagebrush land soils that have a sandy surface layer have a medium- or fine-textured subsoil which will store moisture that infiltrates following snowmelt or large rainstorms. If moisture is relatively abundant during the seedling stage, allowing the establishment of a well-developed root system, then the mature plants can make use of the moisture stored in the subsoil. This can account for the fairly productive crested wheatgrass stands sometimes found on soils that have sandy surface layers.

Gravel or cobbles have somewhat the same effect as sand in that they occupy soil-moisture storage space and cause infiltrating moisture to penetrate deeper into the soil. Again, if crested wheatgrass has established a well-developed root system during a relatively wet period, it may survive and grow rather vigorously during seasons of normal precipitation even in fairly gravelly soils. Indian ricegrass (Oryzopsis hymenoides) or other deep-rooted grasses which are more difficult to establish than crested wheatgrass (Hull, 1962), would take up more of the deep-stored moisture in sandy or gravelly soils than crested wheatgrass.

The soils included in the high moisture-holding capacity group (figure 3) contain more clay than the soils in the medium group. Most of the surface-soils were silty, clay loams and the subsoils were either clay loams or clays. These soils have angular blocky or massive structure and usually are quite hard when dry. These physical properties indicate that these soils cannot admit water as rapidly as those of the medium moisture-retention group. Consequently, runoff is much more likely to occur from the fine-textured soils of the high group. Also, there is more particle surface-area and more pores of a smaller size in fine-textured soils than there is in medium- or coarse-textured soils. Therefore, in fine-textured soils, moisture is held in thinner films and more moisture is unavailable for absorption by plants because it is bound at moisture tensions which are too great. Moisture tension is the magnitude of the force with which moisture is attracted by the soil.

The moisture-holding capacity of the soil is only one of the variables which affects seeding success and grass production. The moisture-holding capacity, in general, increases as the soil texture becomes finer.

The field method of wetting and feeling the soil will usually indicate whether a soil is coarse-, medium-, or fine-textured. Small soil pits will reveal the texture of the subsoil and how deep the soil is normally wetted, as discussed in the field sampling section of this report. The root penetration data shown in table 2 suggest that seeding results were better where moisture penetration was at least 45 to 50 centimeters (18 to 20 inches).

Therefore, it is probably unnecessary to actually measure the moisture-holding capacity of the soil. Areas having soils in the medium textural range, which are normally wetted to at least 20 inches, are the most suitable for seeding in the arid and semiarid west.

Site groups

Practically no statistical correlation was found between crested wheatgrass yield and any of the measured soil, natural vegetation, or estimated precipitation parameters when all of the sites were considered together. Accordingly, sites that had at least one characteristic in common were grouped. The groups that resulted are shown in table 2 along with the variables that probably account for the differences in average grass production among the groups.

The soils data shown in table 2 are from the treated areas of the sites. The data were usually similar for the adjacent untreated areas.

Table 2.--Characteristics of sagebrush-seeding site groups. The top and bottom figures in each cluster define the range of values and the middle value is the group mean. Big sagebrush vigor index was obtained by multiplying the average height by the percent cover.

Group	No. of sites	Crested wheatgrass yield (lbs/A)	Big sagebrush vigor-index	Estimated annual precipitation (inches)	Moisture content at saturation (percent)		Soil profile mean Electrical conductivity (mmhos/cm at 25°C)	pH	Root penetration (cm)
					Surface	Subsoil			
High yield	10	high 2290 mean 1535 low 1010	65.3 40.9 24.2	14 12 11	40.8 32.4 20.2	54.0 37.7 20.7	1.52 .88 .58	7.8 7.0 6.2	80 51 40
Intermediate yield	16	812 386 132	71.8 36.8 14.1	14 10 8	47.8 30.8 17.3	50.4 32.3 22.8	3.11 .88 .33	7.5 7.1 6.7	70 48 30
Cheatgrass competition	7	744 297 46	53.5 40.2 20.5	11 11 11	51.4 39.7 27.8	66.5 50.6 30.8	1.74 1.14 .68	7.0 6.6 6.3	80 58 40
Halophyte	8	608 124 0	37.2 25.9 16.0	14 11 9	41.6 30.1 22.1	46.3 32.0 23.8	5.16 1.94 .59	8.1 7.6 7.4	70 45 30
Big sagebrush failure	8	tr 0 0	55.0 28.1 5.0	11 9 8	45.7 33.4 22.9	48.8 37.3 20.0	1.21 .78 .39	7.7 7.3 6.9	50 41 30
Marden Brush cutter	2	tr 25 50	50.9 38.9 26.9	12 11 10	47.1 41.3 35.6	45.3 39.0 32.7	1.31 1.00 .69	7.4 7.0 6.6	50 47 45
Mean for all sites	51	485	35.1	11	33.3	36.9	1.07	7.1	48

Much complicated verbage would be required to discuss each site separately; instead a table listing the data for each site is presented as an appendix.

Precipitation effects

Plummer et al. (1955), reported that rangeland seedings in the Intermountain region can be successful where average annual precipitation exceeds 10 inches. They further state that careful planting in soil having good moisture-holding qualities has resulted in successful stands where average annual precipitation is as low as 8 inches. According to Hull et al. (1962), seedings have not been successful on areas in Colorado having less than 10 inches of annual precipitation. Reynolds and Springfield (1953) concluded that most of the crested wheatgrass plantings made in big sagebrush types of Arizona and New Mexico with less than 12 inches of average annual precipitation have been failures. In general, our findings on the effect of annual precipitation on the conversion of sagebrush land to crested wheatgrass agree with the conclusions of the above-mentioned researchers.

However, for any particular seeding site, all of the factors that control the effectiveness of the annual precipitation must be considered. The seasonal distribution of the precipitation is very important because the greater the amount of precipitation occurring during the growing periods, from early spring through middle summer and fall, the better are the chances for establishing a good stand of crested wheatgrass which will yield well year after year (fig. 4). Nevertheless, precipitation that occurs during the dormant seasons should not be discounted, especially if it infiltrates the soil and is stored there until the growing season. Another factor of influence



Figure 4.--A site near Woodruff, Utah where the crested wheatgrass yield was over a ton per acre in 1964. The annual precipitation at this site is about 12 inches, but more than one-half of it occurs during the growing season. The soil is loamy textured, appears to be quite permeable, and is about 80 centimeters deep.

is the mean annual temperature which is primarily a function of latitude and altitude, and it, along with the relative humidity and amount of wind, affects the evaporation of moisture from the soil surface and transpiration from plants.

The combination of precipitation and the soil characteristics present a third set of factors which perhaps are as important as the two factors already mentioned. The permeabilities of all except extremely coarse-textured soils limit the amount of water that can be absorbed by the soil per unit of time. Therefore, some of the precipitation that falls during major storm events, other than gentle rain, may run off. The probability of the occurrence of runoff and the amount of runoff both increase as the soil texture becomes finer. The high moisture-holding capacities and limited infiltration rates of clayey soils cause moisture to be stored in them near the soil surface where it is more vulnerable to evaporation than in coarse- or medium-textured soils. Also, the loss of moisture by evaporation can be greater for clayey soils than for coarser textured ones because particle contact is greater and allows for greater upward movement of moisture during the drying phase. Similar infiltration problems and evaporation losses likely exist for soils that have a water-impeding hardpan or solid rock layer that is within about 40 centimeters of the soil surface. However, as previously mentioned, some moisture may infiltrate too deeply into sandy or gravelly soils to be recovered by crested wheatgrass or similarly-rooting plants. If precipitation is great enough during the growing periods, crested wheatgrass production probably will

be satisfactory even though the soils are clayey or coarse-textured. Fair grass production may also result on sites that receive only 8 inches of annual precipitation if the soil absorbs and stores, in the root zone, much of the precipitation that falls, then releases most of the moisture to the plants during the growing season.

Big sagebrush vigor

The decrease in grass yield means as the big sagebrush vigor-index² means decrease for the groups in table 2, tends to support the widely used criterion that the taller, denser, and more vigorous the big sagebrush, the greater the grass production potential of a site. This is based on the assumptions that cheatgrass competition suppressed the crested wheatgrass production of the sites in the cheatgrass competition group, and that the difference between the vigor-index mean of the halophyte group and the vigor-index mean of the big sagebrush failure group is insignificant.

Big sagebrush height, density, and vigor, while useful, are not completely reliable indicators of grassland potential. These sagebrush properties vary with the age of the shrubs, the subspecies and possibly hybrids (Beetle, 1960), grazing, competition from other plants, and disease and insect infestations. These sagebrush variables may explain why some sites support rather productive stands of crested wheatgrass even though the sagebrush was not particularly tall, dense, or vigorous. For instance, the grass production of the site shown in the upper

² The big sagebrush vigor-index was obtained by multiplying the average height in feet by the percent aerial cover for those sites where big sagebrush was the only species or one of the dominant species in mixed types.

lefthand photograph of figure 2 was over 800 pounds per acre in 1963, even though the adjacent sagebrush averaged 22 inches in height and only 11.4 percent aerial cover. After the sagebrush and other competitive plants are eliminated, only the interrelated climatic and soil variables remain to influence the establishment and productivity of the grass stands, provided that suitable seedbed preparations and planting methods are used.

In a few places the actual grass production appeared to be lower than that indicated by the sagebrush characteristics. This is possibly due to the fact that sagebrush has a branching taproot which enables it to extract deeply-stored moisture which cannot be reached by crested wheatgrass roots. Likewise, unpublished data of R. F. Miller and I. S. McQueen suggests that big sagebrush absorbs moisture at tensions somewhat greater than those at which absorption by crested wheatgrass ceases. It should also be recognized that the characteristics of the sagebrush reflect long-time climatic effects. So, if an attempt to convert to grassland is made during a period of one or more years of subnormal precipitation, the full potential of the site may not be developed.

The low values of the means of the big sagebrush vigor-indexes and corresponding crested wheatgrass yields for the halophyte and big sagebrush failure group (table 2) emphasize the low grass production potential of sites supporting open stands of short big sagebrush.

High yield group

The high yield group (table 2) is composed of the 10 highest yielding crested wheatgrass sites. These sites are located in five states on eight seedings. The pretreatment vegetation on nine of the sites was vigorous big sagebrush, usually similar to that shown in figure 5. The pretreatment vegetation on one site was mixed big sagebrush and black sagebrush (Artemisia nova). The sagebrush vigor-index low and mean values are the largest ones when comparing the ~~five~~^{six} groups. The estimated average annual precipitation mean is the largest of all groups, and it is noteworthy that all of the precipitation values for this group exceed 11 inches.

On nearly all of the sites in the high yield group, the surface soils were sandy loams and were underlain by loams or clay loams. All of the soils except one were free of hardpans near enough to the surface to seriously impede water movement. These conditions probably permit water to readily infiltrate into the surface soil; then the finer textured, more compacted soil underneath slows downward movement of the water and holds it in the root zone of the grasses. Runoff is apparently slight. Much of the precipitation that falls becomes soil moisture, which is available to plants.

The mean grass root penetration of 51 centimeters (20 inches), shown in table 2, reflects the mean depth of maximum moisture penetration. At field capacity, approximately 6 inches of water can be held in the root zone of these soils if the average moisture content at saturation of that zone is 35 percent. The 6-inch value was arrived at by estimating the field capacity from the saturated-soil moisture content and estimating the volume of water from soil moisture-density relationships.



Figure 5.--Plowing resulted in a complete kill of this vigorous stand of big sagebrush in southwestern Utah which covered 30 percent of the ground and averaged 26 inches in height. The excellent stand of crested wheatgrass is growing in a soil 20 inches deep having a sandy loam surface underlain by a sandy clay subsoil. Annual precipitation is about 14 inches. Forage production was more than 1,000 pounds per acre in 1964.

Intermediate yield group

The intermediate yield group is composed of sites that yielded less crested wheatgrass than the sites of the high yield group. Nonetheless, the conversions were moderately successful at most of the sites. Several sagebrush species were included in this group. Twelve sites were big sagebrush types; three sites were black sagebrush; and one site was Wyoming sagebrush (Artemisia tripartita, rupicola).

Apparently, the principal reason for the intermediate grass yields (table 2) is that, normally, there is not enough soil-moisture available for abundant grass production. Various factors seem to be responsible for lower than optimum moisture conditions.

The estimated annual precipitation is less than 10 inches for 7 of these sites, including the Wyoming sagebrush site and one black sagebrush site (see appendix). The low precipitation has resulted in grass stands that are either poor (fig. 6) or, on some seedings, fairly dense stands that do not grow vigorously because of intense competition for moisture (fig. 7).

Five sites are in areas having 10 to 12 inches of precipitation, but because of unfavorable distribution of the precipitation and unoptimum soils, there is probably not enough soil-moisture for abundant grass production. Three of the sites have relatively fine-textured soils. When saturated, the moisture contents of their root zones average from 38 to 40 percent. One site has a very fine-textured soil with the moisture content at saturation being about 50 percent. The crested wheatgrass yields for these four sites averaged about 360 pounds per



Figure 6.--The normal productivity of this vigorous but scattered stand of crested wheatgrass near Ely, Nevada is limited to about 500 pounds per acre because the mean annual precipitation is only about 8 inches. The grass is fairly vigorous because there is less competition for moisture than there would be if a full stand existed. The forb is Russian thistle (Salsola kali).



Figure 7.--The normal productivity of this full stand of crested wheat-grass, near Dinosaur, Colorado, is limited to about 350 pounds per acre because the mean annual precipitation is only about 8 inches. This grass is not vigorous because there is intense competition among plants for a limited amount of moisture. The scattered clumps of four-wing saltbush (Atriplex canescens) and big sagebrush also compete for some of the moisture.

acre in 1964. The production of these sites is probably limited to about this level by the adverse moisture-absorbing and moisture-holding properties of the soils. The soil at one site is sandy; when saturated, the average moisture content of its root zone is 26 percent. The low grass production of that site, 132 pounds per acre in 1964, is apparently due to the low moisture-retention capacity of the soil and to the lack of sufficient precipitation during the growing season.

The soils of the black sagebrush sites in this group are gravelly. Small gravel forms a mat on the surface (fig. 8) and occurs in the surface soil. In general, the gravel increases in size and quantity with depth; at 30 to 40 centimeters gravel constitutes at least 50 percent of the lower subsoil. The soil fines mixed with the gravel are moderately fine-textured and appear to be fairly permeable. The gravelly texture of the black sagebrush site subsoils may cause some of the moisture to drain beyond the root system of crested wheatgrass.

On a few other black sagebrush sites, not included in this study, a compact hardpan, containing little gravel, existed from 4 to 6 inches below the soil surface. Infiltration of water into those soils is probably impeded, and the end result is a droughty soil with poor grass production potential.

Crested wheatgrass production averaged 500 pounds per acre on the three sites converted from black sagebrush and 1,550 pounds per acre on three sites on the same seedings, converted from vigorous big sagebrush. These results are not in agreement with the report of Plummer et al. (1955), that adjacent big sagebrush and black sagebrush ranges in Nevada and central Utah yielded similar amounts of crested wheatgrass.



Figure 8.--Treatment of this gravelly black sagebrush site, in north-eastern Nevada, resulted in a vigorous, but scattered stand of crested wheatgrass which yielded 410 pounds per acre in 1963.

Because of their relatively limited grass production potential and the high winter forage value of black sagebrush mentioned by Pechanec et al. (1965), and Plummer et al. (1955), it is questionable whether or not extensive areas of black sagebrush should be plowed and seeded.

On two sites of the intermediate yield group, competition from big sagebrush appeared to be severe enough to prevent high grass production. One of these sites had been plowed and seeded 8 years prior to investigation. The areal cover of the sagebrush, which had reinvaded, amounted to 40 percent of the cover on the adjacent untreated site. Other undesirable features of this site were that the root zone of the soil contained about 35 percent gravel by volume and basalt bedrock existed at 30 centimeters, resulting in a low moisture-holding capacity. At the other site, which had been treated about one year before examination, the cover of big sagebrush was about 30 percent of that on the untreated. Although the grass stand probably was not completely mature, its growth and production were undoubtedly being retarded by the sagebrush competition.

Cheatgrass competition group

The cheatgrass competition group is composed of seven sites where generally poor stands of crested wheatgrass were mixed with cheatgrass brome (Bromus tectorum) and usually Sandberg bluegrass (Poa secunda) (fig. 9). In 1963, the cheatgrass production ranged from 184 to 988 pounds per acre with the mean production being 648 pounds. This was more than double the crested wheatgrass mean yield shown in table 2. The Sandberg bluegrass yield varied from 0 to 594 pounds per acre with



Figure 9.--Crested wheatgrass production at this site, in southeastern Oregon, was suppressed to 450 pounds per acre in 1963, less than one-half that of the cheatgrass and Sandberg's bluegrass which were understory species that became more dense after plowing and seeding.

a mean of 292 pounds per acre which was similar to the crested wheatgrass mean yield. The mean percentage composition by weight of cheatgrass was 52 percent. The amount of cheatgrass present during the seedling stage of the crested wheatgrass is not known, but apparently cheatgrass competition was great enough to prevent the establishment of good stands of crested wheatgrass on all of the sites in this group.

Five sites in this group were on the same seeding and were located very close to each other. Low sagebrush (Artemisia arbuscula) was the only shrub species on two of the adjacent untreated sites and was mixed with antelope bitterbrush (Purshia tridentata) on a third site. The other two sites had quite vigorous big sagebrush (table 2) growing adjacent to them. The moisture contents of the saturated soils were greater than the optimum for establishing crested wheatgrass, but the abundance of cheatgrass and Sandberg's bluegrass, both on the seeding and as understory on the untreated sites, is indicative of the grass production potential of the sites. The pH of all of the soils of the sites on this seeding was near 6.5, which is nearly optimum for the production of most grasses. The rhyolitic parent material plus the buildup of organic matter through time apparently are responsible for the soils being acidic.

The remaining two sites of this group were located on two other seedings. The big sagebrush at one of the sites was moderately vigorous with a fairly dense understory of cheatgrass. The natural vegetation at the other site was a mixture of big sagebrush, rubber rabbitbrush (Chrysothamnus nauseosus), and spiny hopsage (Grayia spinosa) with a

moderately dense understory of cheatgrass. At other sites on these same two seedings, where there was no cheatgrass competition, the crested wheatgrass production exceeded 1,400 pounds per acre.

Particularly in southern Idaho and in some regions of adjacent states, extensive stands of cheatgrass are managed for forage and erosion control, as pointed out by Klemmedson and Smith (1964) in their very comprehensive review of the literature on cheatgrass. In those regions it may be uneconomical to convert extensive areas to perennial grasslands regardless of the fluctuations in production and the fire hazard of cheatgrass. However, if a decision is made to plow and seed any cheatgrass infested area, proper procedures should be employed to greatly reduce the cheatgrass competition so that full production of seeded grass can be obtained as soon as possible.

Klemmedson and Smith (1964) cited the greenhouse study by Evans (1961) who demonstrated that cheatgrass (Bromus tectorum) stands of 64 and 256 plants per square foot severely curtailed shoot and root growth and greatly increased the mortality of crested wheatgrass (Agropyron desertorum), and cheatgrass densities of 4 and 16 cheatgrass plants per square foot moderately reduced the survival and growth of crested wheatgrass. Hull and Stewart (1948) indicated that if cheatgrass is reduced to 50-100 plants per square foot for one season, perennial grass seedlings can become established.

Hull and Stewart (1948) and other workers found that moldboard plowing is the most effective method of eliminating cheatgrass, but moldboard plowing is expensive and can only be done on relatively level, rock-free ground.

Hull and Stewart (1948) and Plummer et al. (1955), have observed that disc plowing can be effective if it is done at the right time. They agree that the best time for reducing cheatgrass stands is in the spring before the seeds form; the next best time is in the fall after the seeds have germinated.

Weather and adverse soil conditions can prevent plowing in the late fall or early spring and these are also the seasons when there is the risk of seeding viable sagebrush seed. However, as two plowings are usually necessary to completely eliminate the sagebrush, probably at least one of the plowings can be done at a time that will result in adequate reduction of the cheatgrass.

Plummer et al. (1955), reported that successful stands of crested wheatgrass resulted when a deep-furrow, disk drill was used to seed into newly germinated cheatgrass stands in Idaho.

Stewart and Hull (1948) have claimed that early summer planned-burning will result in a 75 to 95 percent kill of cheatgrass. They emphasize that the burning should be followed by seeding in the fall to control erosion. Plummer et al. (1955), reported that "burning before the seed shatters is economical and effective." Klemmedson and Smith (1964) have repeated the warning by several authors that the amount of reduction of cheatgrass by summer burning fluctuates from year to year.

Several studies have shown that there are possibilities of controlling cheatgrass on rangelands with herbicides (Robocker et al., 1965; Robocker and Canode, 1965; and Klemmedson and Smith, 1964). Apparently, due to the high costs of the chemicals and the inconsistent results obtained in tests, the above-mentioned authors do not fully recommend the use of herbicides on extensive areas of cheatgrass.

Halophyte group

The halophyte group is composed of sites where halophytic shrubs were mixed with sagebrush prior to treatment (figs. 10 and 11). Usually the treatment completely eliminated the sagebrush and none has reinvaded, but the halophytes shadscale (Atriplex confertifolia), and greasewood (Sarcobatus vermiculatus) usually have reinvaded in appreciable amounts as is shown in table 3 and figures 10 and 11.

Five of the sites have no crested wheatgrass establishment, but they usually support some annual herb, such as cheatgrass, Russian thistle (Salsola kali), or an annual mustard along with the reinvading halophytic shrub. The low average grass yield of 124 pounds per acre points out the general failure of converting shadscale- and greasewood-infested sagebrush lands to grasslands.

Two of the shadscale sites, sites 18 (fig. 10) and 24 in table 3, had hardpans below 25 or 30 centimeters. Those hardpans unquestionably restrict infiltration of water as is indicated by the few weak roots developed in them.

The mean pH and electrical conductivity (E.C.) values of the soil pastes of the halophyte group are the highest values shown in table 2, but these soils have much lower calculated salt contents (U.S. Salinity Laboratory Staff, 1954) than the soils under some pure stands of greasewood and shadscale investigated by Gates et al. (1956), in Utah. In fact, two of the sites in this group have soil E.C.'s lower than the mean E.C. of the 10 high groups. The mean E.C. of the halophyte group surface soils is only slightly higher than the mean for the high yield



Figure 10.--A mixed shadscale, big sagebrush, bud sagebrush site in northwestern Nevada with a very hard, saline subsoil is shown above. Shadscale has reinvaded on an adjacent plowed and seeded area shown below. No crested wheatgrass was established. The herb is Russian thistle.





Figure 11.--A mixed greasewood, big sagebrush, spiny hopsage site in northwestern Nevada with a saline surface soil and a saline-sodic subsoil is shown above. Greasewood and cheatgrass have increased and no crested wheatgrass was established on the adjacent plowed and seeded area shown below.



Table 3.--Comparison of the vegetation on the treated and adjacent untreated Halophyte Group sites at the indicated number of years after treatment.

Site No.: U = Untreated; T = Treated.

Shrub vegetation: *, Few scattered plants, none intercepted in the transect; Arsp, bud sagebrush (*Artemisia spinescens*); Grsp, spiny hopsage (*Grayia spinosa*); Atnu, Nuttall's saltbush (*Atriplex nuttallii*); Tesp, Cottonthorn (*Tetradymia spinosa*).

Site No.	Shrub vegetation				Years after treatment	Crested wheatgrass yield (lbs/A)	Saturated paste	
	Percent cover and average height in feet						Surface soil	Subsoil
	Shadscale	Greasewood	Big sagebrush	Other				
6U	*		21.9, 1.7		8	184	.74	.88
6T	16.0, 0.8		1.0, 1.0				.59	.71
18U	17.0, .9		1.7, 1.5	Arsp .9, .3	4	0	.63	2.19
18T	12.1, 1.0						.71	6.64
19U		10.6, 2.1	6.4, 2.5	Grsp .7, 2.6	4	0	1.29	4.33
19T		18.2, 1.7					2.17	5.42
24U	8.5, 1.5		1.7, 1.5	Arsp .4, .5	3	0	.55	.86
24T							.55	.89
25U	2.3, 1.8		14.0, 1.8		3	0	.47	.98
25T	.5, 1.3						.47	.77
36U			2.1, 1.1	Atnu 7.9, .4	3	200	.67	1.36
36T							1.03	1.34
41U	5.7, 1.1	3.1, 2.2	13.2, 1.6	Tesp .1, 1.4	8	0	.78	1.50
41T	3.3, 0.6						.66	1.75
42U	1.0, 1.0	5.9, 3.3	14.6, 2.0		8	608	.57	.68
42T	.6, .7	3.1, 1.4					.73	1.59

group surface soils, while the halophyte group subsoils are considerably more saline than the high yield group subsoils. Although the salinity levels are probably high enough to reduce the stands and vigor of the plants (U.S. Salinity Laboratory Staff, 1954), the salt-induced osmotic pressure³ of the surface soil, even when the soil moisture content is near the lower limit of available moisture, would not be high enough to greatly reduce germination. The calculated osmotic pressures (U.S. Salinity Laboratory Staff, 1954) for the halophyte group saturated soils average about 1 atmosphere for the surface soil and range between 0.75 and 8.0 atmospheres for the subsoil. Aro (1958), using sodium chloride-calcium chloride mixtures, found that crested wheatgrass (A. desertorum) seedling growth was only reduced to 90 percent of the control at 7.5 atmosphere osmotic pressure. Hass et al. (1962), showed that the crested wheatgrass yield was two-thirds that of the nonsaline control on plots in Idaho made artificially saline to a level similar to the mean salinity of the halophyte group soils.

The osmotic pressure of most of the soils at field moisture levels is probably not extremely high, but when this pressure or tension is added to the soil capillary induced tension, the resultant total soil moisture tension is undoubtedly great enough during dry periods to reduce grass seedling survival.

³ Osmotic pressure is the pressure to which a pool of soil water must be subjected in order to be in equilibrium with a pool of pure water separated from the soil water by a membrane permeable only to pure water.

It appears to be impractical to attempt to convert to grasslands extensive areas where the vegetation is wholly or partly composed of shadscale or greasewood. Poor grass stands are the likely result and reinvasion of the shrubs is probable. These halophytes have winter forage values. If more forage is badly needed or there is a serious runoff and erosion problem, Arcadia-type contour furrowing and seeding, as discussed by Branson (1965), may be effective. Hull (1963) conducted seeding trials at several dry, salty, soil locations in Wyoming, on almost pure Nuttall saltbush (Atriplex nuttallii) types and on mixed types composed of Nuttall saltbush and some or all of several species including shadscale and big sagebrush. Seedling stands of several grasses varied from poor to excellent. However, after 11 to 14 years the stands had deteriorated until they were poor or nonexistent on plots where the seedbeds had been prepared by 1 to 3 of the following methods: moldboard plowed, disked, dragged, or graded. All plants had died on unprepared seedbeds. Russian wildrye (Elymus junceus) and crested wheatgrass (Agropyron desertorum) were the only surviving species; the crested wheatgrass was slightly inferior to the Russian wildrye. Bleak et al. (1965), experimented with the natural and artificial revegetation of the arid shadscale zone, but reported that they succeeded only in defining the problems that remain to be solved.

Spiny hopsage, which appeared on one site in this group and on four sites included in other groups, appears to have indicator significance with respect to the reseeding potential of sites where it occurs. The crested wheatgrass yields were nil for four of the sites and 358 pounds

per acre for the fifth site. A few spiny hopsage plants occurred on one of the saline sites in the halophyte group in association with greasewood and big sagebrush. On the other four sites, the amount of spiny hopsage varied from a few scattered plants, not intercepted in the transect, up to 5.5 percent cover. On these four nonsaline sites, the dominant shrub was fairly vigorous big sagebrush. The surface soil textures for the five sites ranged from sand to silt loam and the moisture contents of the saturated surface-soils ranged from 22.1 to 38.5 percent. This might indicate that spiny hopsage is adapted to a sandy or medium-textured soil habitat, but the salinity status of the soil apparently does not control the presence of spiny hopsage. Spiny hopsage may indicate a soil which cannot hold enough available moisture to sustain crested wheatgrass, but will support shrubs because they are deeper rooted and can extract moisture at higher tension levels. It is also possible that spiny hopsage may be the source of a substance that inhibits germination of crested wheatgrass to such an extent that few seedlings develop. Bonner (1950) does not name spiny hopsage specifically, but reported that some desert shrubs may produce substances toxic to one or more other species.

Big sagebrush failure group

The big sagebrush failure group consists of eight failure sites where the original vegetation was big sagebrush (fig. 12). The vigor-index of the big sagebrush for this group was next to the lowest of all groups (table 2).



Figure 12.--Only a trace of crested wheatgrass resulted from the plowing and seeding of this nonvigorous big sagebrush site having an extremely gravelly subsoil. The precipitation is rather evenly distributed throughout the year with the mean total being approximately 8 inches. The site is in east-central Nevada.

The relatively low mean value for estimated annual precipitation, shown in table 2, partially explains the seeding failures on these sites. At most of these sites, the soils are deep enough and have the proper chemical and physical characteristics to support vigorous, productive stands of perennial grass if precipitation and the resultant soil moisture were less limited.

Four of the sites are located on seedings where the annual precipitation is about 8 to 9 inches. The soils on two of these sites have low moisture holding capacities; possibly there was insufficient moisture held in the surface soil at the right time to promote grass establishment. On another site, the surface soil has a moisture content at saturation of 35.4 percent. Considering the very limited moisture conditions, the soil may be of fine enough texture to prevent the survival of grass seedlings. A silty crust about 5 centimeters thick existed at the soil surface and this may hamper infiltration of water. One site is located on an alluvial fan that had a dense cover of annual mustard, both on the treated area and as an understory species on the untreated area. If the mustard was there during the seedling stage of the grass, the competition for moisture was probably detrimental to the grass. A good stand of grass exists on the part of the seeding that is not on the mustard-covered fan.

On another seeding, there were two sites where the sagebrush had vigor indexes which exceeded 50. One of these sites had a 5.5 percent cover of spiny hopsage along with a 19.6 percent cover of big sagebrush. The moisture-holding capacities of the soils were slightly higher at these two sites than at two other sites on the same seeding where grass had been successfully established.

The soils at two sites on two other seedings were medium-textured but had quite high moisture contents at saturation. Annual precipitation of 11 inches probably does not provide enough soil moisture for strong plant growth. However, one of these sites is located on a stock driveway and grazing during the seedling stage may have contributed to the failure. The other site had been broadcast seeded and, although there had been no crested wheatgrass establishment, there were some western wheatgrass seedlings present when sampled three years after treatment. The western wheatgrass had undoubtedly come from the adjacent untreated area.

Runoff and Erosion

Runoff and erosion do not appear to be serious problems for much of the big sagebrush type. The soils of much of the type are coarse- to medium-textured, and they are usually moderately permeable. Also in areas where the sagebrush-grass type still exists, the plant cover inhibits runoff and erosion to some extent.

In some sagebrush-covered valleys or basins there are gullies, incised in alluvium, that are up to 12 or more feet in width. The gully shown in figure 13 is an example. Depletion of the understories by overgrazing in the past is apparently the main cause of the gullies. In many of the areas there is scant evidence of erosion on the valley bottoms, except near the gullies where there is some rilling. Evidently the water flows across the valley bottoms in shallow, interconnected depressions which wind among the shrubs. As the water nears the gullies it becomes deep enough and flows fast enough to cause noticeable erosion.



Figure 13.--This gully in Long Valley, Nevada is an example of the gullies which exist in the sagebrush type. The gully is about 12 feet wide at the top and about 12 feet deep, but does not seem to be enlarging rapidly. Gullies of this type may not represent serious problems. Nevertheless, gullies are the result of runoff and erosion. Uncontrolled runoff and erosion can be serious problems themselves, and cause other problems such as flooding and sedimentation downstream.

Many of the gullies apparently are not enlarging appreciably. The sediment yields from erosion of the valley bottoms and gully walls are probably low in most instances.

In some areas, particularly those having fine-textured soils or steep slopes, sheet and gully erosion are destroying some sagebrush land. Runoff and sediment from these areas probably intensify flooding or sedimentation problems downstream in the watershed.

Where runoff and erosion are problems, increasing the density of the perennial grasses and other herbaceous species should reduce the severity of the problems. Reduced grazing will improve partially depleted understories, but sagebrush control and seeding may be necessary to improve areas where grasses are badly depleted.

Little quantitative data is available pertaining to the effect on runoff and erosion when sagebrush land is converted to a grassland. The Geological Survey in cooperation with the Bureau of Land Management has a study in progress, in Colorado, which should begin to bridge the above-mentioned data gap.

Other considerations

Most of the preceding sections of this report pertain to soil and climate that may control the successfulness of converting sagebrush lands to grasslands. However, there are some other factors that should be considered before a decision is made to investigate an area for seeding.

Native grass potential

First, it should be determined whether or not the plant cover of the area can be improved by means other than seeding. In areas where remnants of desirable natives remain, a change in the intensity or season of grazing may be adequate. Spraying or burning will frequently eliminate almost all of the sagebrush competition. Desirable natives are then released and substantial improvement in forage production and soil stabilization can be realized.

Costs and benefits

Regardless of the type or intensity of treatment planned for an area, it must be ascertained whether or not the benefits will justify the cost. Fencing is an integral part of many treatment practices and the cost of fencing must be included. Stock water development is often necessary in order to fully utilize treated areas and water development can be rather expensive in some places. The benefits resulting from the improvement of rangeland can be numerous, but aside from the forage production increase, many of the benefits such as runoff and erosion control, wildlife habitat improvement, and undesirable plant control, are difficult to evaluate. Usually an estimate can be made of the forage production increase which will result from the treatment. The longevity of a seeding is important in determining whether or not it is economical. With proper management, a good stand of crested wheatgrass will probably last 25 or more years. Hull and Klomp (1966) have recently reported that some 30-year old crested wheatgrass seedings in Idaho are producing more than a ton of forage per acre.

Several papers describing methods for economic analysis of sagebrush treatments are available. Reports by Lloyd and Cook (1960), Caton and Beringer (1960), Krenz (1962), Pingrey and Dortignac (1959), and Gardner (1961) can be consulted.

Effects on wildlife

In some areas sagebrush provides winter forage for big-game animals, mainly deer. A couple of questions should be answered regarding those areas. Can the deer migrate to other areas where sagebrush will be available if it is eliminated on the proposed treatment areas? Are there steep slopes or rough or rocky areas where treatments are unfeasible, or other areas nearby where sagebrush removal is either unnecessary or undesirable, which will satisfy big game requirements? The effect of treatment on sage grouse should be considered if they inhabit the proposed treatment area.

Conversion procedures

The weather conditions cannot be controlled and the soils cannot be changed appreciably. Nonetheless, suitable treatment methods can be selected and, within limits, be applied at the proper times to increase the chances for the successful conversion of sagebrush lands to grasslands.

Brush elimination

Range workers have long known that the most successful conversions to grasslands have come about where the sagebrush stands were completely destroyed. There are three general means by which sagebrush can be destroyed: mechanical, chemical, and fire.

The three plow-type implements that had been used most frequently for sagebrush elimination on the seedings studied were the brushland plow (U.S. Forest Service adaptation of the Australian stump-jump plow), wheatland disk plow, and the heavy offset disk. Single plowing of some of the areas and double plowing of the others had usually resulted in either a nearly complete or complete kill of sagebrush.

However, ineffective plowing apparently was the cause of unsatisfactory control of sagebrush on a few other seedings which were examined when selecting sites for this study. The detrimental effects of sagebrush competition on seeded-grass establishment and production have been well documented by Blaisdel (1949), Frischknecht (1963), and other workers. Pechanec et al. (1965), Hull et al. (1962), and Plummer et al. (1955), have thoroughly discussed the use of plows and other implements for sagebrush control. They have emphasized that the brushland plow is the plow best adapted for use on rough, rocky, or uneven land; the heavy offset disk is the most effective plow in heavy, compacted soil; and effective use of the wheatland plow is restricted to relatively level, rock-free lands. They have stated that plowing three to four inches deep will usually destroy sagebrush, but if other root-sprouting plants, such as rabbitbrush, are present, the plowing should be five to seven inches deep. Their experience has indicated that the best kills of sagebrush are obtained when it is plowed in late spring or early summer or at other times when the soil contains some moisture. They have advised that mechanical sagebrush control work should not be done during late fall, winter, or early spring after sagebrush seed starts to ripen and before it germinates.

In the last several years, the Marden brush cutter, shown in figure 14, has been used rather extensively on sagebrush land in one Bureau of Land Management district in New Mexico.

Six areas that had been treated with the brush cutter were examined; two of the areas were actually sampled and investigated in detail (table 2). The kill of sagebrush by the brush cutter had been quite inconsistent. On two of the areas examined, nearly all of the sagebrush had been killed and none had reinvaded. Satisfactory stands of grass occupied these two areas.

On the other four areas, the kill of mature sagebrush was good, but most of the younger more limber plants survived. By the second year after treatment the surviving sagebrush had recovered from the treatment-induced injuries and was growing vigorously. The elimination of the older brush apparently had released moisture to the surviving brush and to new brush seedlings which came up after the treatment. Although the cover of big sagebrush had been reduced more than 80 percent by the treatment, there appeared to be about as many sagebrush plants on the treated areas as there were on the untreated, if plants of all ages were considered (fig. 15).

The elimination of rabbitbrush (Chrysothamnus sp.) had also differed greatly. On one of the sites sampled, the cover of rabbitbrush about one year after treatment was only 15 percent of that on the adjacent untreated area. Conversely, at the other site, the one shown in figure 15, the cover of rabbitbrush on the treated area was about double that on the untreated area. The cover was 5.1 percent on the untreated and 11.5 percent on the treated, 2 years after treatment.



Figure 14.--A Marden brush cutter equipped with a broadcast seeder. Use of this machine in northern New Mexico has resulted in sagebrush kills of from about 50 percent up to about 95 percent. Seeded grass establishment usually has been poor as a result of treatment with this machine.



Figure 15.--The scene above is near Cuba, New Mexico. In the foreground is a strip of untreated sagebrush and in the background an area that was treated with the Marden brush cutter. The picture below was taken just inside the fence about two years after treatment. A few clumps of old sagebrush have survived and new big sage seedlings have appeared. The rabbitbrush cover has doubled. Russian thistle and sparse stands of crested wheatgrass and Indian ricegrass make up the understory.



Except for one area, very little crested wheatgrass had become established as a result of broadcasting seed from the back of the brush cutter (see fig. 15). On an area where a good kill of sagebrush had been obtained, a full stand of native western wheatgrass had become established, but no crested wheatgrass was found. On another area the stand of western wheatgrass was increasing even though the sagebrush had not been completely eliminated.

The Marden brush cutter cannot be relied on to reduce stands of sagebrush and associated shrubs adequately or seed grass efficiently enough to allow full stands of grass to become established. One advantage of the brush cutter is that it does not destroy native grasses that may be present to the extent that plowing does. Pechanec et al. (1965), have concluded that rolling brush cutters, such as the Marden brush cutter, do not prepare sites adequately for seeding; they doubt that rolling brush cutters have any real value for eliminating sagebrush on large range areas.

Sagebrush spraying treatments were not intensively investigated during this study. However, spraying with 2, 4-D is a very desirable sagebrush control method in some places.

Certainly, where there is a suppressed understory of desirable native grasses, spraying is a cheap and effective means of improving the range. Hyder and Sneva (1956) in southeastern Oregon and Hull et al. (1952), in west central Wyoming reported 2-to 3-fold increases in perennial grass production the second year after the big sagebrush was sprayed. The sagebrush kill was 83 percent, and the grass production

was about 150 pounds per acre on the unsprayed plots of the Oregon study. The sagebrush kill ranged from 60 to 97 percent in the Wyoming study, and the grass production on the unsprayed plots was about 220 pounds per acre.

Few exact criteria have been published regarding the amount of desirable understory that is necessary to restore a full stand without seeding. Hyder and Sneva (1956) have contended that "a sagebrush-bunchgrass range in fair condition with deep-rooted bunchgrasses yielding about 150 pounds per acre is suited to profitable improvement by chemical control of big sagebrush." Pechanec et al. (1965), suggested that seeding should be done where less than 1/5 of the total plant cover is desirable forage.

In the last several years, some Bureau of Land Management districts in Idaho and Oregon have sprayed sagebrush range that had little or no understory. Crested wheatgrass was planted with a rangeland drill following spraying. Satisfactory stands of grass were becoming established on most of the seedings that were examined (fig. 16). Some advantages of spraying followed by seeding are that (1) spraying leaves the soil less vulnerable to erosion than plowing, and (2) loose seedbed problems are alleviated. However, it must be realized that even a rangeland drill may not operate effectively if the brush is too large or too dense (Pechanec et al. (1965)).



Figure 16.--An area in southeastern Oregon where the sagebrush was sprayed, after which, crested wheatgrass was drilled with a range-land drill. The picture was taken about two years after the area was seeded. Scattered clumps of native bluebunch wheatgrass were present.

Another important use of spraying is the control of sagebrush which has reinvaded seedings. Cook and Lewis (1963) studied a seeded foothill range in central Utah into which sagebrush had reinvaded. They show that for three separate sprayings during three separate years, the average increase of crested wheatgrass was 688 pounds per acre the third year after spraying. A concurrent 2-year study showed a similar increase for tall wheatgrass and an increase about one-half as great for intermediate wheatgrass. The production on unsprayed crested, tall and intermediate, wheatgrass plots was 314, 325, and 624 pounds per acre respectively. The canopy cover of big sagebrush, 71 percent of which had reinvaded the first two years after plowing, varied from 7.6 to 12.3 percent. The kill of brush from 2, 4-D esters, determined the year following treatment, ranged from 58.9 to 96.8 percent.

How large or how dense sagebrush should be allowed to become before spraying is practical is mainly a matter of economics. However, in the interest of maintaining a full stand of vigorous grass it seems advantageous to control sagebrush before the grass production is severely reduced in the area immediately surrounding the brush plants. Frischknecht (1963) found that crested wheatgrass yields were suppressed to a distance of 3 feet from the big sagebrush stem, especially when the crown diameters of the shrubs exceeded 15 inches. Cook and Lewis (1963) determined that the average lateral root spread was 34.4 inches for big sagebrush that was 7 to 8 years old and averaged 13 inches in height. The average lateral root spread for crested wheatgrass of the same age was 23.9 inches. Cook and Lewis (1963) and Frischknecht (1963) have shown

that, in mixed stands, the fibrous roots of both crested wheatgrass and big sagebrush are concentrated in nearly the same vertical zone, even though the taproots of big sagebrush extend deeper than the main body of roots. These data help explain the suppression of crested wheatgrass by big sagebrush.

Krenz (1962) has summarized the general criteria for obtaining good sagebrush control by spraying as follows: (a) use recommended materials, (b) spray when brush is growing actively, and (c) apply properly. Alley (1965) and Hyder and Sneva (1955) emphasize that the effectiveness of spraying decreases rapidly when the lack of soil moisture and high temperatures become critical to sagebrush growth. The time when sagebrush is most susceptible to spray varies with the locality and with the weather conditions of the particular year. Alley (1965) lists some plant indicator criteria to aid in selecting the proper time to spray. He concludes from spraying studies in Wyoming, that the sagebrush twigs should be rapidly elongating, bluegrass (Poa secunda) complex should be in full or past bloom stage, the petals of flowery and hooded phloxes should fall off when the hand is brushed over the plant, and Idaho fescue should be starting to head.

Recent controversies over the use of pesticides point out the need for knowing the effect of a chemical on all of the resources present where the chemical is used.

In the chemical brush and weed control section of the Bureau of Land Management Manual, many literature citations are given to emphasize that normally palatable, 2, 4-D treated forage is not toxic to animals. However, some normally unpalatable, toxic plants such as halogeton become more palatable after treatment with 2, 4-D. Livestock are usually kept off sprayed areas for one or two years after treatment, but it is much more difficult to prevent the use of sprayed areas by wildlife.

Present knowledge of the effect of spraying on wildlife environments and water resources is limited, but continuing research should answer many questions.

The elimination of rabbitbrush normally requires treatments that are more specific or more intensive than those which effectively eliminate sagebrush. Hyder et al. (1958), experimented with the chemical control of green and grey rabbitbrush (Chrysothamnus viscidiflorus and C. nauseosus) in central and southeastern Oregon. They found that both species were more susceptible to 2, 4-D esters than the several other herbicides that were tried. Good rabbitbrush control was obtained when it was sprayed at the proper time with 2, 4-D at an acid equivalent rate of 3 pounds per acre. The 2, 4-D was prepared either in water or diesel oil emulsion and was applied at a total volume of 5 to 10.9 gallons per acre. Their tests showed that maximum green rabbitbrush susceptibility followed the first occurrence of good sagebrush susceptibility by 3 to 5 weeks. Nevertheless 96 percent of the big sagebrush that was mixed with the green rabbitbrush was killed by the spraying that gave the maximum

green rabbitbrush kill of 90 percent. A spraying test in one abnormally dry year resulted in a poor kill of green rabbitbrush. They have suggested a preliminary index of green rabbitbrush susceptibility to 2, 4-D which is as follows: "New rabbitbrush twig growth must exceed 3 inches in length, Sandberg bluegrass (Poa secunda) must have reached flowering development, squirreltail (Sitanion hystrix) and Thurber needlegrass (Stipa thurberiana) must be heading and Sandberg bluegrass herbage must retain some green color." Robertson and Cords (1957) have offered similar plant phenology aids for determining the susceptibility of rabbitbrush (Chrysothamnus nauseosis and C. viscidiflorus elgans) to 2, 4-D from the results of spraying trials near Elko, Nevada. They likewise have noted that high available soil moisture probably provides growth conditions most favorable for herbicidal action on rabbitbrush.

Other treatments which Robertson and Cord (1957) found effective in the control of rabbitbrush were root planing when soil moisture was nearly depleted, controlled burning in summer or early fall, burning followed by spraying, and spraying the same area two years in succession.

Planned and controlled burning has not been used extensively for sagebrush control in recent years by the Bureau of Land Management. Nonetheless, Pechanec et al. (1954), found, in Idaho, that burning is effective in improving sagebrush-infested range if: (a) the area can properly be burned, (b) it can be burned at the proper time and in the proper manner, (c) the fire can be adequately controlled (d) careful grazing management is provided after burning including the exclusion

of grazing or trailing for a full year, and (e) the area can be seeded the first fall after burning if there is less than a 20 percent cover of perennial grasses and weeds. Pechanec et al. (1954), showed that 15 years after burning the grazing capacity on burned range was 60 percent greater than on adjacent unburned range due to improved forage production and availability. Sagebrush had regained only 25 percent of its pre-treatment production after 15 years.

Planting methods

Over 80 percent of the sites studied were seeded with either range-land or grain drills; the remaining sites were broadcast seeded. No direct comparisons were made between drilling and broadcasting as to their effect on seedling establishment. There were both successful seedings and seedings that failed regardless of the seeding method. Notwithstanding, on a few sites where seed was broadcast, it appeared that a better grass stand might have resulted if the seed had been drilled. The seed will be in closer contact with the soil-moisture for a longer time if it is drilled than if it is broadcast. Plummer et al. (1955), have declared that, "Drilling is preferable to broadcasting wherever land surface conditions permit because less seed is needed and because the seed is more evenly distributed and more adequately and evenly covered."

Data on the type of furrow openers used, the drilling depth and the spacing of drill rows was not collected. Nevertheless, these factors are important to the success of seeding, so a brief discussion of the recommendations in the literature regarding them seems worthwhile.

Plummer et al. (1955), recommended semideep disk openers which leave a small furrow for general use in range reseeding. They elaborated further that, "Where moisture is not limiting, ordinary single-disk furrow openers give as good a stand as semideep types." Results of a study by McGinnies (1959) confirmed the observations of other workers that, where moisture is limited, the best stands of grass are obtained by using a drill equipped with deep-furrow openers. McGinnies listed three possible beneficial effects of deep furrows on soil moisture; (1) scraping away dry surface soil permits the seed to be planted in moist soil; (2) furrows collect runoff; and (3) less moisture is lost from the bottom of deep furrows than shallow ones due to more protection from air movement and heat. Deep-furrow lister drilling is reported to be beneficial when seeding into stands of cheatgrass (Hull and Stewart, 1948). Most writers have cautioned that deep-furrow openers should not be used where the soils are likely to slough or blow, thus covering the seed too deeply. McGinnies mentioned that seedlings in furrows may be smothered when water, ice, or snow cover them too long.

Optimum planting depth is mainly a function of the size of the seed. The larger the seed, the deeper it can be covered. One-half inch is the generally suggested drilling depth for crested wheatgrass seed (Hull and Holmgren, 1964; Hull et al., 1962; Plummer et al., 1955). The depth should be increased to one inch for sandy soils or soils that dry rapidly.

Tests in southern Idaho (Hull and Holmgren, 1964), "showed no difference in ultimate herbage yield of stands at any row spacing up to two feet. As the rows are spaced farther apart, less seed is required, but more years are required to attain full production." Plummer et al. (1955), asserted that 6 to 8 inch drill-row spacings have several advantages over wider spacings. For the first three to five years, 6 to 8 inches spacing results in smaller plants which are more readily grazed. Close, 6-to 8-inch, spacings also provide more soil protection and more competition against weeds and brush reinvasion. On drier sites, "where there is a premium on moisture for plant survival, row spacing of 10 to 14 inches are best," according to Plummer et al. (1955).

Loose seedbeds which allowed the seed to be planted either too deeply or seed in poor contact with the soil particles were sometimes mentioned by Bureau of Land Management personnel as a cause of the failure of some seedings. Hull et al. (1962), and Plummer et al. (1955), stressed that on loose or rough seedbeds, drills should be equipped with depth bands and packer wheels. McGinnies (1962) found that packing of a loose, fine sandy loam seedbed either before or after drilling increased crested wheatgrass seedling establishment. Cultipacking of the entire soil surface three times before drilling produced the largest increase. Packing of bands into which the seed was drilled produced the second largest increase. Cultipacking of the entire surface once was the third best treatment. Only slight increases in grass seedling establishment resulted when the packing treatments were applied to a coarser, sandy loam soil. McGinnies concluded that packing before drilling provided a firm seedbed and allowed depth bands to work more effectively.

Planting time

Nearly all of the seedlings studied were planted in the fall. The exact planting date information was not always available, but September, October, and November were the months most often given.

Planting during middle and late fall allows germination and seedling development to progress during the spring when favorable moisture and temperature conditions persist the longest time. Spring seeding has been successful in certain areas where sufficient precipitation occurred after planting to establish seedlings hardy enough to survive summer drought periods. Early fall planting is advisable (Plummer et al., 1955) where there is sufficient precipitation for germination and seedling development before the onset of cold weather. The risk with early fall planting is that there may be only enough moisture during the fall for partial germination and partial seedling development. As a result, the seedlings may die before they can utilize moisture which is available in the spring.

Species and rates

Studies of other workers have indicated that crested wheatgrass (Agropyron desertorum) fairway wheatgrass (A. cristatum) and Siberian wheatgrass (A. sibericum) are the species best adapted to the relatively dry environments of most of the seedlings that were studied. Crested wheatgrass is the species most frequently recommended. Relative ease of establishment, drought endurance, and ability to withstand heavy grazing are the main features which make these species the most suitable for relatively dry areas. Russian wildrye is another species adapted

to dry areas and has additional advantages of being more salt tolerant and palatable for a longer season than crested wheatgrass. However, it is more difficult to establish good stands of Russian wildrye. Plummer et al. (1955), discovered that the small seedlings were sensitive to frost and drought, but that planting in furrows aided in the establishment of Russian wildrye. Indian ricegrass is another species which is frequently mentioned in the literature as being adapted to dry areas, but it is also difficult to establish. Intermediate wheatgrass (Agropyron intermedium), and pubescent wheatgrass (A. trichophorum) are two sod-forming species that reportedly do well on areas where the annual precipitation exceeds 12 inches. Complete information on the adaptation and recommended use of many species has been compiled by Hull and Holmgren (1964), Hull et al. (1962), and Plummer et al. (1955).

Crested wheatgrass drilling rates of 5 to 7 pounds per acre had been used most frequently on the seedings of this study. Broadcasting rates of 8 to 10 pounds per acre had been used most frequently. These rates are similar to those recommended in the literature.

Grazing control

The value of fencing treated areas so that grazing can be deferred or controlled is universally recognized. New seedings should not be grazed the first year and only lightly, if any, the second year. Thereafter the seedings can be grazed at any intensity that is consistent with good range management and conservation. Plummer et al (1955), recommended that on level areas, 30 to 40 percent of the crested wheatgrass herbage

be left to maintain the vigor and productivity of the stand. On sloping areas where more protection from erosion is needed, 50 to 60 percent of the herbage should be left.

SUMMARY

Fifty-one plowed and seeded, and adjacent untreated sites on 22 Bureau of Land Management crested wheatgrass seedings in the sagebrush type of seven States were studied. The vegetation conversion results that were obtained on those seedings are the basis for the following general criteria for selecting areas to be converted from the sagebrush type to a perennial grassland type in the arid and semiarid regions of the west.

1. Before plowing and seeding, be certain that the understory of desirable perennial forage species is so sparse that the range cannot be converted to a grassland by spraying or burning the sagebrush.
2. Normally, seeding should be restricted to areas where the annual precipitation exceeds 10 inches.
3. Use indicator plants:
 - a. Consider the height, density, and vigor of big sagebrush as indicators of the grass production potential of an area. Confirm the indications of the sagebrush by evaluating the climatic and soil characteristics of the area.
 - b. Avoid treatment of areas that have open stands of short big sagebrush.

c. Moderately successful seedings can be obtained on black sagebrush land, but the seeding potential is usually lower than it is on vigorous big sagebrush land in the same area.

d. The seeding potential on areas that have shadscale or greasewood or spiny hopsage mixed with sagebrush usually is low. Avoid treating areas where shadscale or greasewood form an appreciable part of mixed types.

4. Limit seedings to areas having soils with the following properties:

a. The soils should be medium textured. Their moisture contents when saturated should be between 25 and 40 percent.

b. The depth of shrub root penetration and/or the depth to a hardpan, caliche layer, gravel layer, or bedrock should be at least 40 centimeters (16 inches).

c. Avoid saline and sodic soils.

d. Avoid soils having a rock content exceeding 40 to 50 percent by volume and soils with rocks large enough to hamper operation of equipment.

5. Plow or disk sagebrush during the late spring or summer when there is some soil moisture. Plow during those seasons to prevent the planting of viable sagebrush seed. A second plowing may be necessary to kill all of the sagebrush and eliminate hard-to-kill species such as rabbitbrush. Spray sagebrush in the spring when it is growing rapidly.

6. Reduce cheatgrass competition by early summer plowing, burning, or chemical spraying before seeding perennial grasses.

7. Drill an adapted species in the late fall unless late spring and summer or fall precipitation is sufficient to sustain seedlings that result from planting immediately prior to these seasons.

8. Fence the seeding and protect it from grazing for at least the first two years.

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Appendix A.--Summary of data from sagebrush-seeding sampling sites in Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, and Wyoming

Explanation of appendix table headings and symbols used: Shrub type cover and height: Artr, *Artemisia tridentata*, big sagebrush; Arar, *A. arbuscula*, low sagebrush; Arno, *A. novae*, black sagebrush; Artru, *A. tripartita*, Wyoming sagebrush; Arsp, *A. spinescens*, bud sagebrush; Ch--, *Chrysothamnus* species, rabbitbrush; Chva, *C. Vaseyi*, rabbitbrush; Grsp, *Grayia spinesa*, spiny hopsage; Atco, *Atriplex confertifolia*, shadscale; Atnu, *A. nuttallii*, Nuttall's saltbush; Seve, *Sarcobatus vermiculatus*, greasewood; Tesp, *Tetradymia spinosa*, cottonthorn; (--,--) first figure is percent cover, second figure is height in feet.

Brush elimination and seeding method and species seeded: OD, offset tandem disk; (2), operation done twice; WP, wheatland one-way plow; BP, brushland plow; P, plowing implement of unknown type; MBO, Marden tandem brush-cutter; ? data unavailable; RD, rangeland drill; B and CD, Seed broadcast with ground equipment and dragged with log-chain; GD, Drilled with grain drill; D, drilled but type of drill unknown; B, broadcast; Agde, *Agropyron desertorum*, crested wheatgrass; Agsl, *A. sibiricum*, Siberian wheatgrass.

Percent moisture at saturation: Weight of water per unit weight of dry soil times 100; surface soil, usually the top 10 to 15 centimeters, normally considered the A horizon; subsoil, remaining hydrologically-active part of profile.

Field method texture: Texture determined by wetting and feeling soil; S1, silt(y); S, sand(y); L, loam; C, clay; g, gravelly; co, cobbly; f, fine.

Electrical conductivity: Units in millimhos per centimeter at 25 degrees centigrade, value converted from a resistance measurement of the saturated paste.

Soil depth: Depth of deepest moisture penetration as indicated by the presence of roots, soil structure and consistence; cl, compact layer, usually containing more clay or more caliche than the material above it and may or may not significantly impede moisture; g, gravel; br, bedrock which is often fractured.

Computed maximum moisture holding capacity: Estimated amount of moisture which the root zone can retain against gravity; computed by estimating the field capacity from the moisture-content at saturation and converting to volume of moisture by using a moisture-density curve, then multiplying by the depth of the root zone.

Estimated rock content: Ocular estimate of all fragments exceeding 2 millimeters in size.

Topographic setting, slope and exposure: Numbers refer to slope in percent; F, flat, no slope and no directional exposure; N, S, W, E, compass directions of exposure.

BLM District	Project Name	Study site number	Site group (table 2 in text)	Seeded grass est.yield (pounds per acre)	Shrub type, percent ground cover and average height, in feet, of major shrub species on adjacent untreated sites	Brush elimination, seeding method, dates; grass species seeded, seeding rate (pounds per acre)	Altitude (ft.)	Est. Annual precipitation (in.)	Soil properties										Topographic setting of site, slope in percent and exposure	Remarks concerning (1) a single site, (2) the comparison of two or more sites on one seeded area, or (3) all of the sites on one seeded area.
									Percent moisture at saturation		Field method texture		Electrical conductivity (umhos)	Saturated paste pH	Soil depth(cm) depth to and type layer which may affect moisture-storage	Computed max.moisture holding capacity of soil (in.)	Est.rock content by volume (percent)	Probable parent material		
									Surface	Subsoil	Surface	Subsoil								
Vale	Rock Creek Seeding	13 14	high yield cheatgrass competition	1,820 456	Artr (16.7,2.2) Artr (21.2,2.1)	OD-10/61,RD-11/61,Agde 5-7 do	4,300 4,300	12 12	38.7 27.8	45.0 41.1	S1L S1L	S1L S1L	1.01 1.50	7.0 7.2	60 50,cl-15	8 6	10 5	basalt basalt	rolling plain, 2-N rolling plain, F	No cheatgrass understory in the untreated sagebrush at this site. Grass production was less than site 13 because of cheatgrass competition.
Vale	Hooker Creek Seeding	8	chestgrass competition	744	Arar (9.4,0.7)	WP-1961,RD-fall 1961, Agde 7	5,000	11	36.0	66.5	S1CL	S1C	1.39	6.5	70	10	25	volcanics	alluvial slope,7-W	The soils of all sites on the Hooker Creek seeding are moderately fine-textured and are probably the reason for the presence of the <i>Artemisia arbuscula</i> . These sites have moderate potential for crested wheatgrass production but cheatgrass competition has been detrimental.
		12	do	242	Artr (12.5,3.4)-Arar(2.6,1.5)	do	5,000	11	47.7	60.2	L	S1L	1.74	6.6	80	11	0	do	alluvial slope,3-NW	
		11	do	154	Arar (15.2,1.5)-Putr (10.5,2.2)	do	5,000	11	37.6	50.0	SL	gSCL	0.89	6.5	40, br-40	5	45	do	alluvial slope,6-SW	
		9	do	82	Artr (16.2,3.3)	do	5,000	11	51.4	49.0	S1L	S1L	0.81	6.3	45, br-40	6	10	volcanics	do 7-W	
		10	do	46	Arar (26.5,1.1)	do	5,000	11	38.8	46.3	S1L	S1CL	0.99	6.4	50	7	10	do	do 6-W	
Boise	Gresmere Halogeton Seeding	5	high yield	1,440	Artr (22.4,1.8)	OD(2)-fall 1952,B and CD fall 1952, Agde 6	5,100	12	36.5	52.0	S1L	S1CL	1.52	7.0	45	6	tr	basalt	rolling plain, F	Crested wheatgrass production still high and very little reinvasion of sage 13 years after treatment
Boise	Big Bill Seeding	7 6	intermediate yield halophyte	492 184	Artr (17.8,1.1) Artr (21.9,1.7)-Atco (few scattered plants)	CD-fall 1955, B-fall 1955,Agde-7 do	5,000 5,000	12 12	17.3 26.1	23.5 23.8	gFS coS1L	gS1L gS1L	0.68 0.67	7.1 7.6	30, br-30 30	2 3	35 25	basalt basalt	rolling plain 5-S rolling plain F	Gravelly, shallow soil. Forty percent reinvasion of sagebrush. Much more shadscale on the treated area than on the adjacent untreated area.
		Elko	Tule Seeding	1	High yield	2,020	Arno (7.7,0.8)-Artr(5.1,1.25)	OD(2) 8/61,RD-10/61,Agde-5	5,900	12	40.8	54.0	SL	SCL	1.01	7.0	50	7	10	volcanics
4	high yield			1,680	Artr (19.5,1.5)	do	5,900	12	20.2	31.3	SL	SCL	0.71	6.6	50	5	0	do	Alluvial slope, 2-W	Sustained production for a period of years will probably be less.
3	high yield			1,480	Artr (26.3,2.2)	do	5,900	12	27.3	20.7	S	SL	0.76	6.2	40, cl-30	3	10	do	alluvial slope, 7-W	Compact layer probably beneficial because it retards deep infiltration of moisture.
2	intermediate yield			406	Arno (16.6,0.8)	do	5,900	12	24.8	22.8	SL	gSL	0.82	6.8	35, g-20	4	35	do	alluvial slope, 7-W	The soil is coarse-textured and its rock content increases with depth.
Winnemucca	McClary Seeding	15	high yield	1,400	Artr (21.7, 2.1)	BP-9/59, B and CD 10/59, Agde-7.5	4,700	11	33.8	33.8	fSL	fgSL	0.59	7.1	50	6	10	do	alluvial slope, 2-NW	Permeability and moisture-storing properties of the soil appear to be excellent.
		20	Cheatgrass competition	358	Artr (11.9, 2.1) -ch (2.8,1.8) Grsp(2.2, 2.8)	OD(2) 9/59,RD-10/59, Agde-7.5	4,400	11	38.5	30.8	SCL	SCL	0.68	7.0	70	8	10	do	flood plain, F	Sites 16 and 17 have finer textured soils and slightly higher moisture-holding capacities than site 15. Therefore, moisture is probably held at higher tensions at sites 16 and 17.
		16	big sage failure	tr	Artr (23.9,2.3)	OD(2) 9/59, B and CD 10/59, Agde-7.5	4,600	11	35.0	40.6	fSL	S1L	1.06	6.9	50	6	10	do	flood plain, 1-W	Only about one foot of soil above basalt flow rock. Subsoil is probably too saline for crested wheatgrass survival on this site. Same as above.
		17	do	0	Artr (19.6,2.7) Grsp (5.5,2.6)	do	4,500	11	38.5	40.4	S1L	S1L	0.89	7.2	30, br-30	4	5	do	flood plain, 1-W	
		18	halophyte	0	Atco (17.0,0.9)-Artr (1.7,1.5)-Arsp(0.9,0.3)	OD(2) 9/59, RD 10/59, Agde-7.5	4,400	11	33.0	34.0	S1L	S1L	3.67	8.1	30, cl-25	4	10	do	flood plain, 1-NW	
19	halophyte	0	Save (10.6,2.1)-Artr(6.4,2.5)-Grsp(0.7,2.6)	do	4,400	11	28.9	25.5	SL	S1L	3.80	7.6	70	6	20	do	flood plain F			
Winnemucca	East Buttermilk Seeding	21	intermediate yield	812	Artr (11.4,1.8)	OD 7/60, GD 11/60, Agde-8	4,800	9	32.9	26.3	SL	fgSL	0.46	7.2	70 g-50	7	15	do	alluvial slope, 3-S	Grass stand and production on this site is remarkably good, considering the dryness of the area.
		22	intermediate yield	508	Artr (21.6,1.6)	OD 7/60, GD 11/60, Agsl-7	4,800	9	29.7	28.6	SL	SL	0.65	7.0	70	7	10	do	alluvial slope, 3-S	Siberian wheatgrass on this site and sites 23, 24, and 25.
		23	big sagebrush failure	0	Artr (8.8,2.5)	do	4,800	9	29.1	28.9	SL	SL	0.65	7.0	40	4	5	do	alluvial slope, 2-S	Fawcett competition may have caused failure on this site.
		24	halophyte	0	Atco (8.5,1.5) Arsp (0.4,0.5)	do	4,800	9	28.0	27.0	fSL	fgSL	0.72	7.4	40, cl-30	4	5	do	alluvial slope, 4-S	Native shadscale indicates a drought soil in which moisture is held at high tensions.
		25	halophyte	0	Artr (14.0,1.8) Atco (2.3,1.8)	do	4,800	9	29.4	30.9	SL	gFSL	0.59	7.7	40, cl-40	4	10	do	alluvial slope, 5-S	Removal of the shrubs has released a stand of vigorous halogeton.
Ely	Willow Creek Seeding	29	intermediate yield	386	Artr (29.9,2.4)	OD fall 1961, GD spring 1962, Agde-5	6,800	8	26.8	29.8	SL	SL	0.58	7.5	70	7	5	limestone	alluvial slope, 4-E	Above normal precipitation has aided grass establishment and production on this seeding.
		30	intermediate yield	250	Arno (26.4,0.9) Artr (0.4,1.1)	do	6,800	8	38.5	28.0	gSL	gSL	0.48	6.8	40, g-20	5	25	limestone	alluvial slope, 4-E	This black sage site is adjacent to site 29. Soil is shallower and more gravelly than the soil of site 29.
		27	intermediate yield	148	Artr (31.3,1.8)	do	6,700	8	25.2	30.2	gSL	gSL	0.56	7.5	70, g-20	3	30	limestone	alluvial slope, 2-E	Grass stand rather poor on this site.
		26	big sage failure	0	Artr (23.6,1.0)	do	6,700	8	23.6	36.2	gFSL	gSL	0.46	7.7	40, g-20	3	40	limestone	alluvial slope, 2-E	Sagebrush vigor was very low on sites 26 and 28. The soils apparently have enough surface area that the moisture was held at tensions that were too great for seedling survival.
28	big sage failure	0	Artr (5.0,1.0)	do	6,600	8	35.4	38.4	SL	SL	0.60	7.6	40	5	20	limestone	alluvial slope, F			
Brigham City	Woodruff Seeding No. 2	35	high yield	2,290	Artr (25.0,2.5)	P-1962, D-fall 1962, Agde-7	6,900	12	31.7	31.7	S1L	S1L	0.89	7.0	80	10	15	sandstone	alluvial slope, 13-SH	An ideal soil and a relatively low evaporation rate result in abundant crested wheatgrass production.
		34	intermediate yield	799	Arno (18.6,0.5) Artr (1.3,0.6)	do	7,000	12	--	--	gS1L	gS1L	--	--	40, g-30	--	40	--	rolling plain, 13-SE	Soil samples were lost. Good results for a black sage site.
		36	halophyte	200	Atnu (7.9,0.4) Artr (2.1, 1.1)	do	6,800	12	41.6	46.3	L	L	1.23	7.5	60	8	0	sandstone and shale	alluvial slope, 3-E	Grass lacked vigor. Soil is rather compact. Probably a significant amount of water runs off this site.
Murray	Erickson Pass Seeding	43	high yield	1,210	No data but assume vigorous Artr Artr (14.6,2.0) Save (5.9,3.3) Atco(1.0,1.0) do Artr (13.2,1.6) Atco (5.7,1.1) Save (3.1, 2.2) Tesp (0.1, 1.4)	P-fall 1956, D-fall 1956, Agde-6	5,800	13	32.4	38.1	f1S	L	0.58	7.8	45	6	tr	granite	alluvial slope, 4-S	Crested wheatgrass grows quite vigorously on this seeding.
		42	halophyte	608		do	5,800	13	32.1	34.7	L	coSL	1.61	7.9	40	4	10	and	alluvial slope, F	Good stand of crested wheatgrass mixed with scattered greasewood and shadscale.
		41	halophyte	0		do	5,500	13	22.1	33.6	S1L	CL	1.20	7.4	50	5	25	slate	alluvial slope, 1-SW	Moisture probably held at tensions too high for grass survival.
Kanab	Findlay Reseeding	44	high yield	1,010	Artr (29.7,2.2)	P-61, D-61, Agde-6	6,500	14	26.7	33.8	fSL	L	0.49	7.2	40	4	5	sandstone	alluvial slope 3-S	Relatively high precipitation compensates for high evaporation in the area.
Vernal	Donkey Flat Seeding	33	intermediate yield	132	Artr (20.1, 1.1)	OD-1953, GD-1953, Agde-6	5,600	10	24.3	27.9	SL	SL	0.78	6.8	35, br-35	3	20	sandstone	plateau, F	Sagebrush lacked vigor. Site had been heavily grazed.
Lander	Disban Butte Reseeding	37	high yield	1,050	Artr (24.2,1.0)	BP 7/52, D-8/52, Agde 10	6,800	12	36.3	36.5	S1L	gL	0.95	7.2	50	6	5	sandstone	rolling plain, 2-S	Slight reinvasion of sagebrush. Some western wheatgrass present.
Lander	Fuller Reseeding	38	intermediate yield	513	Artru (20.8, 0.2)	P-9/52, D-11/52, Agde-?	5,300	8	32.6	36.7	SL	SCL	1.05	7.5	50	6	0	sandstone claystone sandy claystone	rolling plain, 5-N	Grass production surprisingly good considering the dry climate and rather fine-textured soil.
Casper	Anda Sagebrush Reseeding	40	intermediate yield	375	Artr (17.6, 0.8)	BP-5/55, D-10/59 2nd time, Agde-10.5	6,600	11	47.8	50.4	SL	SL	1.19	6.9	40	6	0	sandstone	rolling plain, 5-S	Sagebrush not too vigorous. Moisture probably held at rather high tensions.
		39	big sage failure	0	Artr (9.4,0.6)	do	6,600	11	44.5	48.8	SL	SL	1.02	6.9	35	5	0	and shale	rolling plain, 1-W	Grazing and trailing on this area when the seeding was new may have killed the grass.
Craig	Stateline Revegetation	32	intermediate yield	316	Artr (11.8, 1.7)	WP-5 or 6/61, RD-9 or 10/61,Agde-6 do	6,000	8	21.9	24.4	S	SL	0.33	7.2	70, cl-10	4	0	sandstone	alluvial slope, 2-N	The compact layer probably caused more moisture to be retained in the surface-soil of site 32 and provided more favorable conditions for grass establishment than on site 31.
		31	big sage failure	0	Artr (17.0, 2.0)		6,000	8	22.9	20.0	S	S	0.89	7.6	50	4	0	sandstone	alluvial slope, 2-S	
Montrose	Roubideau Contours	48	intermediate yield	158	Artr (30.7, 1.2) Atca(1.6,1.2)	? ,RD-spring 1963,Agsl-5	6,600	13	31.5	29.6	S	SL	0.73	7.0	60	7	5	sandstone	plateau, 1-N	About 50 percent sagebrush kill, but fair stand of wheatgrass has resulted in a good multiple-purpose range site.
Durango	Finch Reseeding	46	intermediate yield	400	Artr (28.0, 2.1)	WP-10/61, D-10/61, Agde-4-5	6,800	10	40.4	40.0	fSL	CL	0.76	7.3	45	6	0	sandstone	plateau, 2-S	Good stand of grass but production was low in 1964 due to a dry spring.
		47	intermediate yield	150 est.	Artr (22.2,2.0)	P-fall 1950, D-fall 1950, Agde-7	6,900	10	33.7	45.1	SL	SCL	0.76	6.7	40	6	0	sandstone	plateau, 2-N	Crested wheatgrass is mixed with native grasses but production was low in 1964 due to a dry spring.
Farmington	Pablo Candelario Sagebrush Eradication and seeding	49	intermediate yield	230	Artr (28.2,1.5)	WP 9/61, B 9/61, Agde-4-7	6,300	12	34.7	41.9	fS	fSL	0.90	6.7	55	7	0	sandstone	plateau, F	Dry spring in 1964 probably resulted in less than average grass production.
Albuquerque	Cajita Reseeding	50	Marden Brush Cutter	50 est.	Artr (12.8,2.1) Cbva (7.3,0.7)	MBC-10/61, B 10/61, Agde-7	7,600	10												

